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# A Detector for Precision Study of High Energy $e^+e^-$ Annihilations: The ECFA/DESY Design for TESLA

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# 1 Physics at a High Energy Linear Collider

A high-energy linear  $e^+e^-$  collider designed to operate in the c.m. energy range around and above 500 GeV is an obvious next step for particle physics investigations of the origin of mass and the mechanism of electroweak symmetry-breaking, and searches for new dynamics such as Supersymmetry (SUSY). The collider represents a natural facility for discovery and precision measurement of new particles [1], and would complement the physics potential of the LHC. For example, for  $M_H \sim 100\text{GeV}$ , favoured by current data, tens of thousands of clean  $H^0$  bosons per year would be delivered at design luminosity.

The anticipated event sample comprises:

- Multijet states containing heavy flavours, *eg.*

$$\begin{aligned} e^+e^- &\rightarrow Z^0 H^0 &&\rightarrow f\bar{f} b\bar{b} / c\bar{c} / \tau^+\tau^- \\ e^+e^- &\rightarrow t\bar{t} &&\rightarrow bW^+ \bar{b}W^- \\ e^+e^- &\rightarrow t\bar{t} H^0 &&\rightarrow bW^+ \bar{b}W^- b\bar{b} \\ e^+e^- &\rightarrow H^0 A^0 &&\rightarrow t\bar{t} t\bar{t} \\ e^+e^- &\rightarrow \tilde{t}\tilde{t}^* &&\rightarrow \tilde{\chi}^0 c \tilde{\chi}^0 \bar{c} \end{aligned}$$

Events such as these require a high-resolution tracking system with excellent secondary decay vertex resolution. Jet energies will typically be in the range  $50 \rightarrow 200$  GeV, and the track momentum distribution will peak around 2 GeV/c, so multiple scattering will be important and necessitate low-mass tracking detectors.

- Events with missing energy, *eg.*

$$\begin{aligned} e^+e^- &\rightarrow \tilde{l}^+ l^- \text{ or } \tilde{q} \tilde{q}^* \\ e^+e^- &\rightarrow \tilde{\chi}^+ \tilde{\chi}^- \text{ or } \tilde{\chi}^0 \tilde{\chi}^0 \end{aligned}$$
- and perhaps exotic processes, *eg.*

$$\begin{aligned} e^+e^- &\rightarrow \tilde{\chi}^0 \tilde{\chi}^0 &&\rightarrow \tilde{G} \gamma \tilde{G} \gamma \\ e^+e^- &\rightarrow G \gamma \end{aligned}$$

due to gauge-mediated SUSY breaking and extra compact dimensions, respectively. Such signatures demand a hermetic calorimeter with good energy resolution and high granularity for energy-flow measurement. This will allow precise jet-jet invariant mass determination and reconstruction of new heavy states above a large combinatorial background. Exotic signatures comprising photons and large missing energy also motivate consideration of a continuous event readout mode with a software trigger [2].

## 2 Accelerator and Detector Environment

The TESLA collider [1, 3], utilising superconducting RF cavities for the main linac, is being designed by an international consortium based around DESY. The collider operates in a ‘one-shot’ mode at a frequency of 5 Hz. In each cycle a train of 2820  $5 \times 550\text{nm}^2$   $e^-$  bunches meets a similar  $e^+$  bunch-train, with a bunch separation of 337 ns. The resulting backgrounds for the detector require careful planning. For example, at  $\sqrt{s} = 500$  GeV one expects, *per bunch crossing*:

- $\sim 120\text{k } e^+e^- \Rightarrow$  a large detector B-field;
- $\sim 1000 \gamma$  in tracking volume  $\Rightarrow$  highly granular tracking system, and possible bunch tagger with time resolution  $\leq 100\text{ns}$ ;
- several TeV EM energy in the forward regions:  $\theta < 100$  mrad  $\Rightarrow$  shielding and masking;

as well as  $\sim 10^9$  neutrons/cm<sup>2</sup>/year, requiring shielding of the inner detector.

## 3 Overview of Detector Design

A schematic of the current design is shown in Fig. 1. The general concept is a large detector with a gaseous main tracking chamber and a hermetic, highly granular calorimeter. A first iteration was presented in [1]. The design is evolving, and R&D is underway in all areas, but the options and technology choices are being focussed and refined. A brief summary of the current thinking is given below.

### 3.1 Vertex Detector (VXD)

The requirements are high granularity (for low occupancy), low mass (for low multiple scattering), good spatial resolution (for precise vertex-finding), and neutron radiation tolerance (see above). A multi(4 or 5)-layer ‘self-tracking’ device would be optimal. CCDs and LHC-style active pixel sensors (APS) are being considered; all are radiation hard at the expected level. Large-area CCD arrays have been ‘combat tested’ at SLD/SLC and offer  $< 4\mu\text{m}$  space-point resolution in  $20 \times 20\mu\text{m}^2$  pixels, with the possibility of devices as thin as  $0.12\% X_0/\text{layer}$ . The APS pixels will be larger ( $50 \times 50\mu\text{m}^2$ ) and thicker ( $0.8\% X_0/\text{layer}$ ), but are more radiation tolerant. CMOS pixel devices have also been suggested and may allow CCD-like resolution with higher radiation

tolerance. A 3 or 4 T solenoidal magnetic field would confine most of the background  $e^+e^-$  flux within the beampipe, allowing the vertex detector to be placed close to the beamline, with the first layer perhaps as close as 1cm.

### 3.2 Tracking System

A large-volume time projection chamber (TPC) offers high effective spatial granularity and yields low occupancy in the expected background  $\gamma$  flux. With a compensating coil to achieve  $\Delta B/B \simeq 0.2\%$  a momentum resolution  $\Delta p_t/p_t \simeq 4.5 \times 10^{-5}$  (4T) could be achieved. A wire-chamber TPC readout offers a useful degree of particle identification, with  $\pi/K$  separation up to or beyond  $p = 20$  GeV/ $c$ . Other possible readout technologies, such as gas electron multipliers and micromesh gaseous structures, are under active development. An ‘intermediate’ tracker would provide linking hits between the VXD and TPC; two planes of  $50 \times 500 \mu\text{m}^2$  pixels appear to be sufficient. Several planes of silicon pixels ( $50 \times 200 \mu\text{m}^2$ ) and crossed strips ( $50 \times 25 \mu\text{m}^2$ ) are also planned to improve tracking performance in the forward regions  $7^\circ < \theta < 30^\circ$  from the beamline.

### 3.3 Calorimetry

Currently thinking is to put the electromagnetic and main hadron calorimeters inside the solenoid. These would be roughly  $25 X_0$  and  $5\text{--}6 \lambda_0$  thick, respectively. Several options are being considered: a ‘tile’ calorimeter based on a sandwich of absorber and scintillator with wavelength-shifting fibres taking the signal out; the same materials, but in a ‘Shashlik’ (nearly longitudinal fibres) configuration; and a ‘high-granularity’ calorimeter based on highly-segmented W/Si or Pb/scintillator or Pb/Ar for the electromagnetic part and W, Fe or Pb with gas chambers for the hadronic part. The first two options would have  $\sim 3 \times 3 \text{cm}^2$  transverse segmentation and coarse longitudinal segmentation, with  $O(10^5)$  channels; the third option might have  $1 \times 1 \text{cm}^2$  transverse segmentation with readout of every layer, yielding as many as  $10^7$  channels. All three options are roughly comparable in terms of their energy resolution:  $10\%/\sqrt{E}$  (or better) (EM) and  $40\%/\sqrt{E}$  (had). The high-granularity option offers additionally superb photon and neutral hadron identification capability.

### **3.4 Muon System**

Space limitations prevent an adequate description, but an instrumented return yoke is being considered for the muon identification and tracking system, as well as to provide a tail-catcher hadron calorimeter. Iron instrumented with gas chambers, such as resistive plate chambers or streamer tubes, provides a well-tested and robust technology base for strip and pad readout systems.

## **4 Future Milestones**

A detailed technical design report for both the TESLA collider and detector is in preparation, and will be presented in spring 2001, with subsequent evaluation by the German Science Council. A decision on this multinational project might be made as early as 2002, with construction starting in 2003. This would allow turn-on in 2009, just a few years after the startup of the LHC, providing a powerful partnership for exploration of new physics.

## **References**

- [1] TESLA Conceptual Design Report, DESY 1997-048.
- [2] G. Eckerlin, these proceedings.
- [3] P. Delahaye, these proceedings.

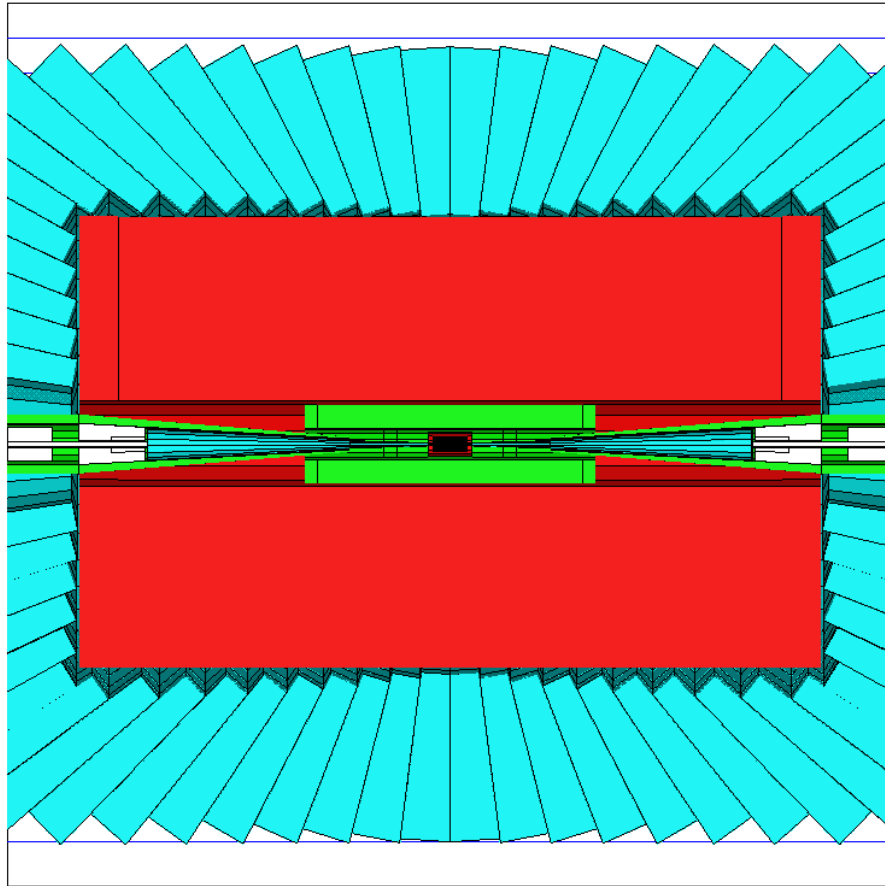


Figure 1: Current detector layout; scale:  $6 \times 6\text{m}^2$ .